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# Ultrafast Laser Pulses on Magnetic Thin Films

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**Abstract:** We are developing a theory and experiment to investigate the dynamic interaction between heat, light and magnetism. We have simulated the temperature distribution produced by a series of ultrafast laser pulses. We will then calculate the magnetic response and test in metamaterial structures.

## Project in Brief

Ultrafast laser spectroscopy techniques [1] have been used to study magnetisation dynamics on extremely short picosecond time scales.

The interaction between optical laser pulses and a magnetic material produces many different phenomena; magnetic spin waves, surface acoustic waves, thermal excitations etc.

In this project we are studying the interplay between all these different phenomena with the goal of creating novel functionalities using patterned metamaterial structures.

## Background

Magnonics is a field of magnetism which studies collective spin excitations in magnetically ordered materials [2]. These magnons have great potential as information carriers with applications in computing, wireless transmission and sensing.

The magneto-optical Kerr effect (MOKE) describes the change in polarisation and intensity of reflected light from a magnetised surface [3]. We drive and measure magetic phenomena at picosecond time scales using this effect with femtosecond pulse lasers (Fig. 1).

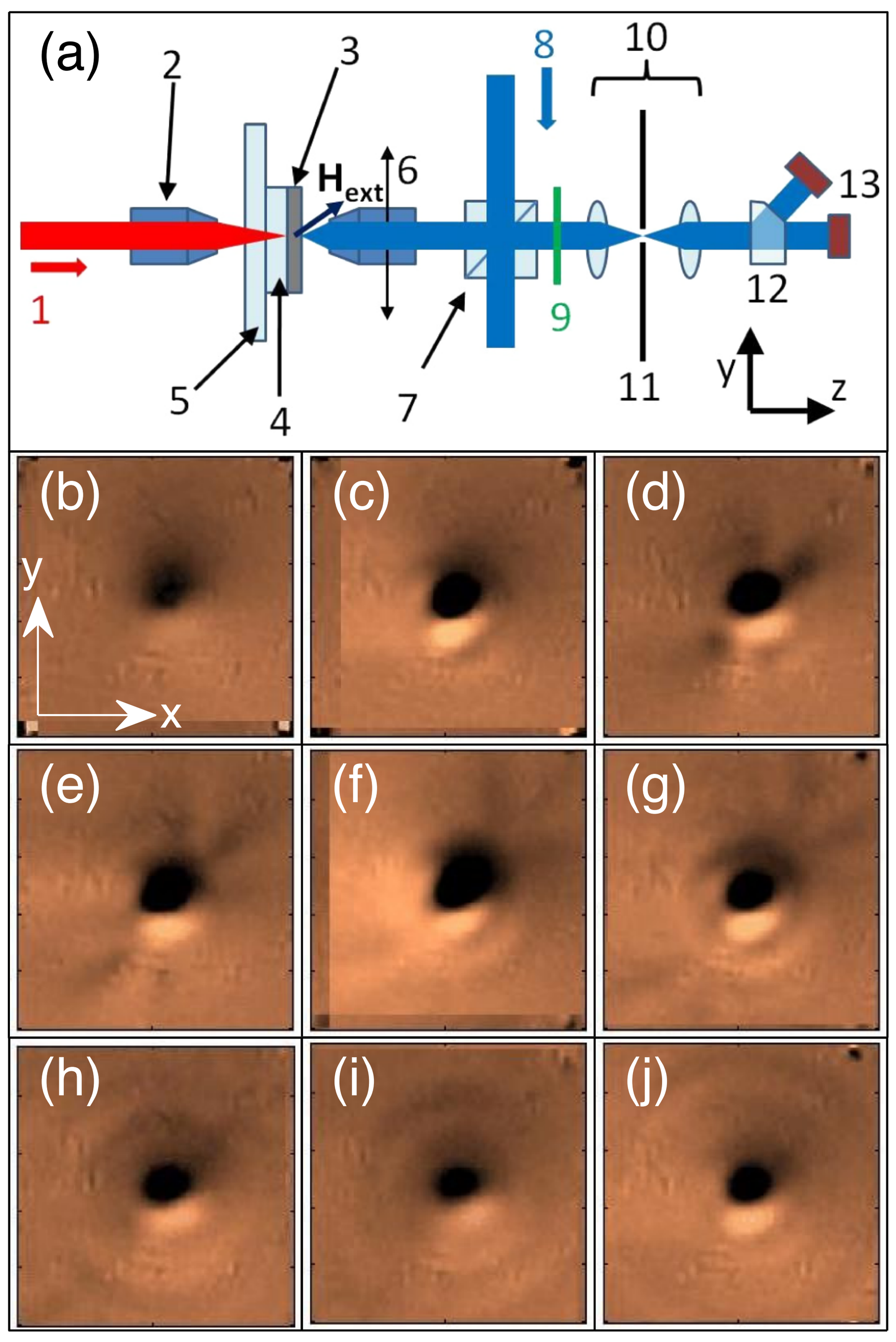


Fig. 1 from [1]:
(a) Schematic of a Kerr microscope:
(1) 800nm wavelength pump beam
(2) Pump beam objective
(3) 50nm thick permalloy film
(4) 430μm thick sapphire substrate
(5) 0.17mm thick glass coverslip
(6) Probe beam objective
(7) Non-polarising beam splitter
(8) 400nm wavelength probe beam
(9) 400nm band-pass filter
(10) Spatial filter
(11) Diaphragm with a 50nm pinhole
(12) Polarising beam splitter
(13) Photodiodes

(b)–(j) Time resolved 10 x 10μm MOKE images at times; 0.667, 1.000, 1.200, 1.267, 1.367, 1.450, 1.567, 1.733, and 2.017ns.

The pulse arrives at 1ns (c). Shortly after at 1.2ns (d) a dark X-shaped beam pattern can be seen, which propagates away from the centre. At 1.367ns a circular ripple emerges, which radiates outwards. These images demonstrate the inherent non-linearity of magnon dispersion.

Temperature field (**T**), with thermal diffusivity $\alpha$ and heat source **Q** describe heat transport in the heat equation:

$$\frac{\partial \mathbf{T}}{\partial t} = \alpha \nabla^2 \mathbf{T} + \mathbf{Q}$$

## Heat Transport Model

The first stage of our investigations requires a detailed analysis of heat in an ultrafast Kerr microscope. We have solved the heat equation numerically using COMSOL for a typical setup (Fig. 2).

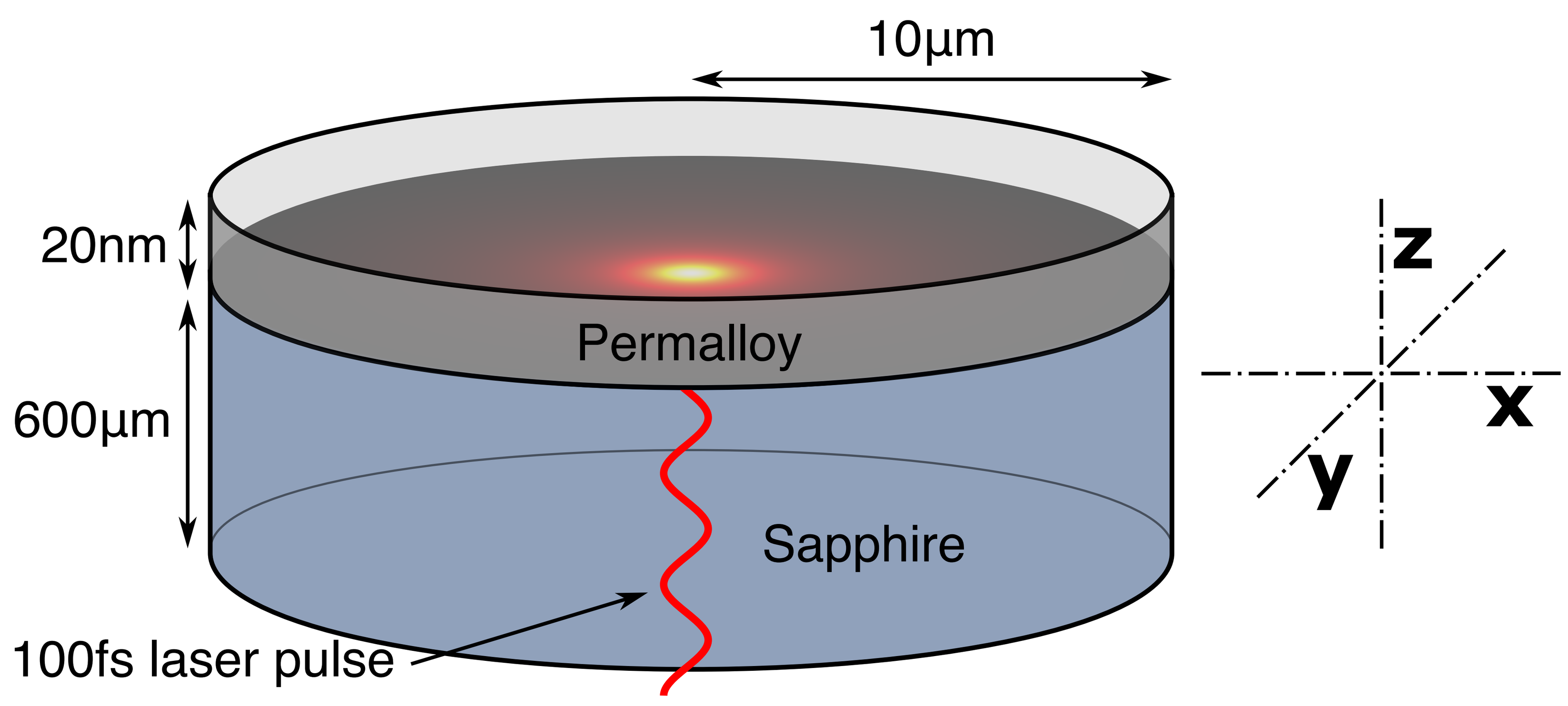


Fig 2. Diagram of our model set up with static simulation results superimposed. A 800nm ultrafast laser pulse travels through a transparent sapphire substrate, heating the bottom of a permalloy film. It is fully absorbed, heating the surrounding area, dissipating into the sapphire. The results shown are calculated for an infinite series of pulses with a 12.5ns seperation.

Assuming axial symmetry, constant room temperature at the edges and no heat loss from the top, we are able to simulate the dynamics at extremely short time scales, as shown in Figs. 3 & 4.

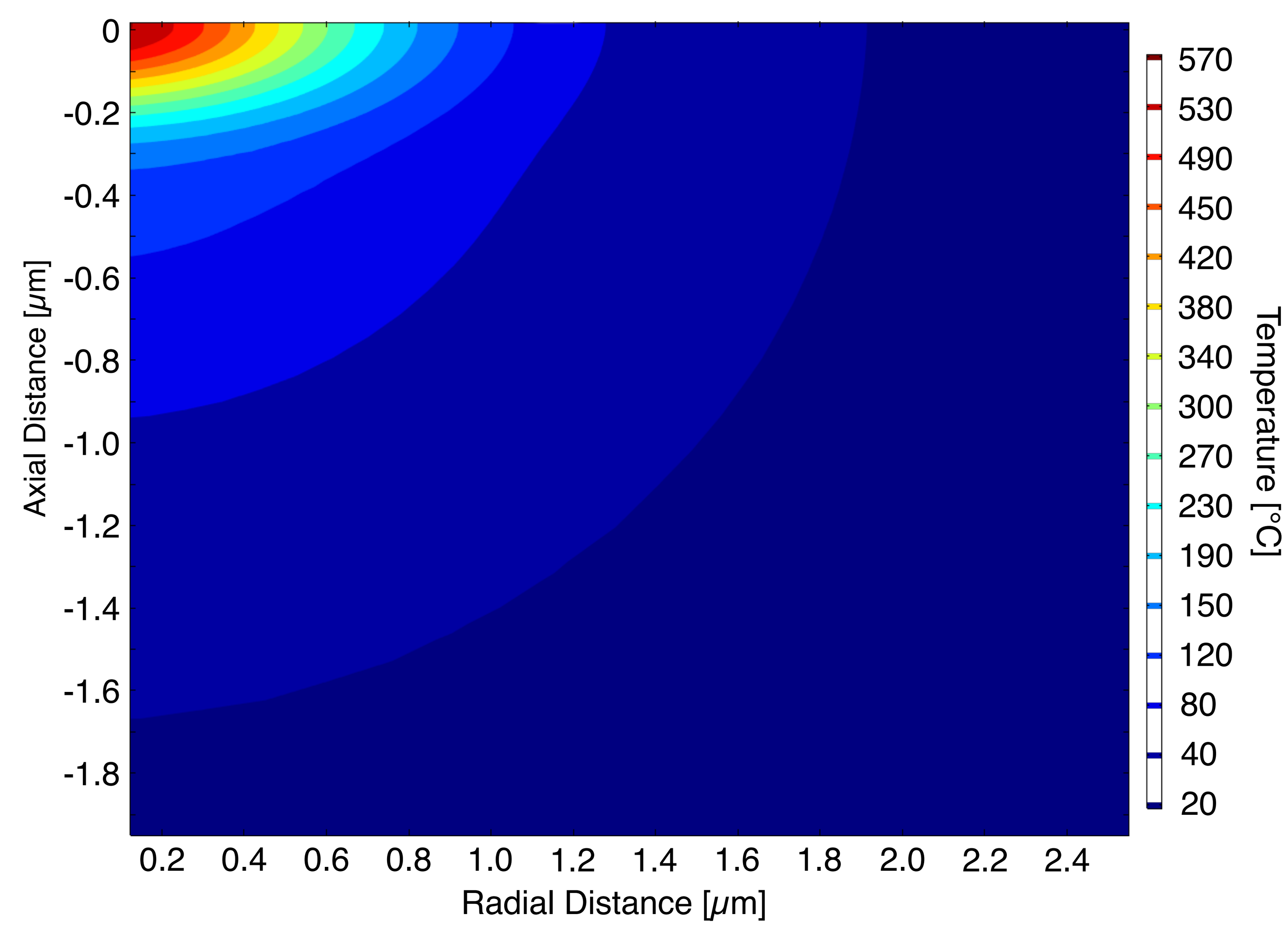


Fig. 3: Temperature distribution 100ps after 10 pulses of heating. An elliptical distribution can be seen at the epicentre of the pulses, which tends to a spherical distribution by ~1.5μm.

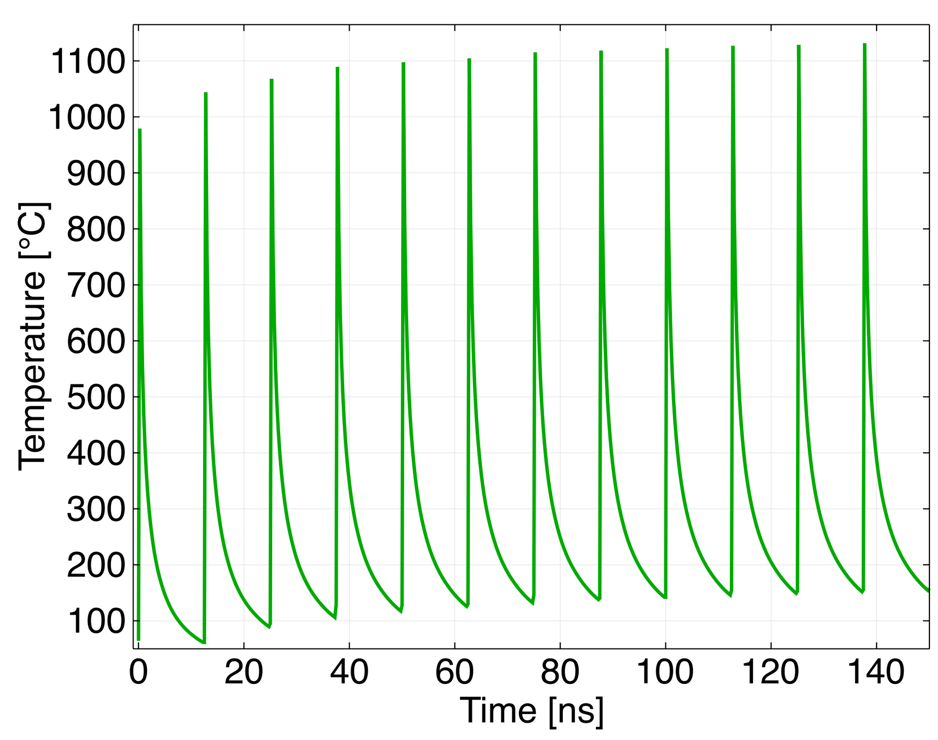


Fig. 4: Temperature of the permalloy surface at the centre of the sample. Each peak and decay represents a single pulse. After about 10 pulses the maximum and minimum temperatures remain the same; a dynamic equilibrium is reached.

Finding the form of this equilibrium allows us to simplify the model to a single pulse. This will then allow an analytical description, which can be used to test the accuracy of the model.

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## References

[1]: Y. Au *et al.*, Phys. Rev. Lett. 110, 097201 (2013)
[2]: V. V. Kruglyak *et al.*, Phys. D - Appl. Phys. 43, 264001 (2010)
[3]: P. S. Keatley *et al.*, J. Appl. Phys. 105, 07D308 (2009)

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